Combined Drying and Grinding of Biomass in One Operation – CRADA 0681
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A CRADA Project with First American Scientific Corporation – Dr. Sundar Narayan

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Significance and Background Information, and Technical Approach

First American Scientific Corporation (FASC) has developed a unique and innovative grinder/dryer called KDS Micronex. The KDS (Kinetic Disintegration System) combines two operations of grinding and drying into a single operation which reduces dependence on external heat input. The machine captures the heat of comminution and combines it with centrifugal forces to expedite moisture extraction from wet biomass. Because it uses mechanical forces rather than providing direct heat to perform the drying operation, it is a simpler machine and uses less energy than conventional grinding and drying operations which occur as two separate steps. The entire compact unit can be transported on a flatbed trailer to the site where biomass is available. Hence, the KDS Micronex is a technology that enables inexpensive pretreatment of waste materials and biomass. A well prepared biomass can be used as feed, fuel or fertilizer instead of being discarded. Electricity and chemical feedstock produced from such biomass would displace the use of fossil fuels and no net greenhouse gas emissions would result from such bio-based operations. Organic fertilizers resulting from the KDS Micronex grinding/drying process will be pathogen-free unlike raw animal manures.

Phase I Project has Demonstrated Technical Feasibility

The focus of Phase I was to demonstrate the feasibility of using KDS as a packaged combined grinder and dryer. We conducted roughly 25 tests on the modified versions of the existing KDS machine in order to evaluate the effect of innovative design changes on the system performance. Each test lasted at least 2 hours to establish a steady state for taking data. A considerable amount of time was spent on preparing the machine and the test material. Data recorded included input and output moistures, feed rate, airflow rates, dry bulb and wet bulb of the exhausted air, rotor housing temperature, and electrical power consumption. The performance criteria were percentage points and quantities of moisture removed, biomass throughput and specific power (or specific energy) consumption. In most cases we also conducted tests on the particle size and particle distribution on each processed sample. We also have done a complete cost analysis of the system which will be presented below. In some cases, the particle size distribution (PSD) of the product was measured. It may be mentioned that the KDS, which was invented to be a grinder, can grind wood to a median diameter of 250 microns. In the case of glass or other minerals, the median diameter can be as low 10 - 30 microns.

Rotor speed

The KDS Micronex was run at two different rotational speeds (2265 rpm and base case 3002 rpm). This was accomplished by changing the sheave sizes of the belt drive. It was not possible to run the machine faster than its usual rpm of 3002, because of vibration problems. Deinking sludge was used as the test substance. Ample deinking sludge was available and this provided a convenient means of conducting extended tests. The results are shown below in Table 2 where MC stands for moisture content on a wet basis. Table 1 shows that reducing the rotor speed from 3002 to 2265 rpm produced the same final moisture content of 34% in spite of a higher moisture content for the sludge tested with 3002 rpm. Although the amount of moisture removed in higher speed test was double of that in lower speed test but the throughput of the two tests were not different to the same extent.

Table 1. Combined grinding and drying of deinking sludge – the effect of rotor speed

RPM	Feed Rate (kg/h)	Feed MC (%)	Production Rate (kg/h)	Product MC (%)	Drying Rate (kg/h)	Power Consumption (kW)	Drying Energy (kJ/kg)
2265	1047	40	952	34	95	70	2652
3002	1240	44	1052	34	188	130	2489

It was also observed that the power consumption at the lower speed of 2265 RPM was less than ½ of that when the speed was increased 30% to 3005 RPM. The aerodynamic drag resistance on the spinning chains was less at 2265 rpm than at 3002 rpm. At higher rotational speeds, the air movement caused by the blades is more intense. As is well-known, convective mass transfer rates are higher at higher air speeds. And the frictional heat due to the aerodynamic drag increases as the square of the rpm - this, too, would cause more drying at higher rotational speeds. This discovery has major implications for the proposed Phase II project, as will be described later.

Rotor design

We tested the performance of the two rotor designs: 13 mm thick blade rotor vs. chain rotor. We used deinking sludge as the test material. Table 2 summarizes the results from processing deinking sludge. The power consumption with the chain rotor was almost twice as the power consumption with the blade rotor. The throughput and the final moisture content of the sludge for the two set-ups were almost the same.

Table 2. Combined grinding and drying of deinking sludge – the effect rotor design

Rotor design	Feed Rate (kg/h)	Feed MC (%)	Production Rate (kg/h)	Product MC (%)	Drying Rate (kg/h)	Power Consumption (kW)	Drying Energy (kJ/kg)
Blades	1280	42	1125	34	155	70	1625
Chains	1240	44	1052	34	188	130	2489

The power consumption of the main drive motor of the KDS Micronex is mainly due to the aerodynamic drag of the spinning chains or blades. The tip speed of the chains or blades was measured at 200 m/s for 3002 rpm rotational speed. One method to reduce the aerodynamic drag was to reduce the rpm of the KDS Micronex which resulted in drop in throughput of the machine. The other method was to use blades which had a low C_dA. C_dA is the product of the drag co-efficient and the projected area. We concluded that blades were clearly superior to chains in terms of the drying performance.

Air circulation

This series of experiments aimed at finding out if increasing the vapor vent flow rate would change the performance of the machine. Ambient air was introduced into the KDS Micronex machine through a valve in the blower inlet. This served as the make-up air and had the good effect of dramatically reducing the air entry through the outlet valve on the cyclone. Because of the size of the valve in the blower inlet, more make-up air could now be allowed in. This increased the air flow rate out of the vapor vents from the base case of 16.4 m^3/m to about 25 m^3/min.

The air flow measurements showed that the recirculating blower in the KDS machine has a discharge rate of 156 m^3/min (5511 scfm). Out of that, 16.4 m^3/min (579 scfm) of air leaves through the 2 vapor vents along with up to 7.5 kg/min of liquid water in the form of a fine mist. When the blower inlet valve was fully closed, the steady state wet bulb and dry bulb temperatures of the air at the blower outlet while processing deinking sludge were almost identical at 56°C ; the relative humidity therefore was 100 %. When the blower inlet valve was fully open, the corresponding temperatures were 50°C for dry bulb and 44.4 °C for the wet bulb; thus the relative humidity was about 77 %. In spite of a decrease in RH at the outlet, no significant differences between the two cases in terms of the water removal rates or drying energy could be observed.

From the recirculation tests, we concluded that with the present design of the machine, lowering the relative humidity of the recirculating air did not lead to increased drying rate – at least for the range of relative humidities tested in these experiments. It is very likely that the residence time of the material inside the KDS machine is not long enough for extra drying to take place. However, relocation of the recirculating vent to near blower reduced the air leakage in the cyclone which improved the solid gas separation function of the cyclone.

Supplemental heat

In this experiment, the hot gases from two construction space heaters each rated at 40,000 Btu/hr were injected into the inlet side of the recirculating blower. This was equivalent to 67.8 kW or about half of the shaft power supplied by the main drive motor. The output temperature of the two burners were measured at 150°C. At steady state with no material being processed, the air temperature inside the grinding chamber was measured to be 104°C. The dry and wet bulb temperatures of the air at various locations on the KDS Micronex were also recorded.

The deinking sludge to be processed was fed at a rate of 909 kg/h into the machine. The temperature of the sludge was 10°C and the sludge had a moisture content of 34 %. The air temperatures inside the KDS started to decrease once the feeding in of the sludge began. When a steady state was reached, the grinding chamber air temperature had dropped to around 60 °C which is the upper limit for temperatures usually experienced without supplemental heat. The exhausted humidity dropped to 44% from its usual 100% when supplemental heat was added. However we did not record any substantial drop in moisture content of the material.

We speculate that part of the heat input was spent to heat up the solid biomass to its operating temperature (50-60°C) and the remaining heat escaped from exhaust. This result may also reinforces our understanding of the machine that perhaps dehydration is not only due to moisture vaporization but also due to other mechanisms such as forces exerted on biomass particles from centrifugal and impact actions .

This discovery too has implications for the Phase II design of the proof of concept KDS Micronex dryer-grinder. The low relative humidity suggests that the recirculating air which conveys the product from the grinding chamber to the cyclone outlet has the potential to absorb more moisture from the powder that it is conveying. Though the air temperature is only 60°C, calculations show that the mass transfer coefficient of particles that are being conveyed will be quite high due to their small diameter and high velocities. Given enough residence time, additional low temperature evaporation of the moisture in the conveyed powder should take place. See the discussion under the headings "Air Circulation" and "Supplemental Heat" which suggests that, at present, the residence time of the powder is not long enough.

Overall Performance

Table 3 summarizes data for testing the performance of the KDS in grinding and drying a variety of biomass material. The machine dried 395 kg/h of deinking sludge from an initial moisture content of 54 % (on a wet basis) to a low final moisture content of 12 %, while also grinding it to reduce its particle size and consuming 75 kW of electrical power. This translates to a water removal rate of 190 kg/h or 0.05278 kg/s. The energy consumption was 75/0.05278 = 1421 kJ/kg or 395 kWhr per metric ton of water removed. In contrast, the most efficient thermal dryers consume around 4000 kJ/kg (4 GJ/metric ton), or about 3 times as much. The KDS consumes electricity rather than natural gas which is a common fossil fuel used in a drum dryer. At the time of writing, the typical prices of natural gas and electricity in the U.S. are $6 per GJ and $0.055 per kWhr. Thus, the drying cost per ton of water removed is $21.73 with the KDS Micronex and $24.00 in the case of a natural gas fired drum dryer. With present prices for electricity and natural gas, the KDS drying cost is about 10 % less expensive than that of a drum dryer. It is widely expected among futures traders that natural gas prices will increase much faster than the price of electricity. With all the improvements described later, the Phase III KDS machine will very likely have a smaller energy consumption than 372 kWhr/ton. Such a low energy consumption will further improve the economics of the KDS technology.

The corn silage mentioned in Table 3 was in a fermented state and was more than 6 months old. It may be mentioned that a drum dryer uses up to 7 GJ of heat to remove a ton of water from corn silage. Table 3 shows that the KDS consumes only 4.4 GJ/ton of energy to do the same.

Table 3. The overall performance of combined grinding and drying of the KDS Micronex

Substance	Feed Rate (kg/hour)	Moisture In (%)	Power (kW)	Output Rate	Moisture Out (%)	Water Removal	Water Removal

				(kg/hour)		Rate (kg/hour)	Energy (kJ/kg)
Deink Sludge	1204	51	110	797	26	406	974
Deink Sludge	395	54	75	205	12	190	1419
Layer Manure	2062	47	130	1713	34	349	1339
Cow+Chicken Manure	1377	40	130	1087	24	289	1614
Bagasse	938	34	110	755	18	183	2163
Corn Silage	326	58	110	236	42	90	4400
Wood Chips	2878	32	150	2718	28	160	3375
Wood Chips	430	43	130	272	10	158	2962

The research done in Phase I has proven that the KDS Micronex which was originally designed as a pure grinder exhibits the technical feasibility to be used as a grinder that also performs drying, without needing external heat input.

Conclusions

The feasibility tests on KDS during Phase I showed that a prototype machine can be developed, field tested and the technology demonstrated for commercial applications. The present KDS machine can remove up to 400 kg/h of water from a wet feed material. Since biomass processors demand a finished product that is only 10 % moist and most raw materials like corn stover, bagasse, layer manure, cow dung, and waste wood have moisture contents of the order of 50 %, this water removal rate translates to a production rate of roughly half a ton per hour. This is too small for most processors who are unwilling to acquire multiple machines because of the added complexity to the feed and product removal systems. And the economics suffer due to small production rates, because the labor costs are a much larger fraction of the production cost. The goal for further research and development work is to scale up the KDS technology incorporating findings from Phase I into a machine that has superior performance characteristics.